

The University of Chicago

FOOD RESERVES IN RELATION TO OTHER
FACTORS LIMITING THE GROWTH
OF GRASSES

A PART OF THE DISSERTATION SUBMITTED TO
THE GRADUATE FACULTY IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF BOTANY

By
LAURENCE FREDERICK GRABER

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CHICAGO, ILLINOIS

Reprinted from
PLANT PHYSIOLOGY
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L. F. GRABER¹

(WITH FOUR FIGURES)

The immediate applied significance of the pronouncements of LIEBIG (1840) with reference to mineral nutrition of plants, not only gave rise to profound changes in soil culture and crop husbandry, but also furnished the basis of the present fertilizer industry. The classic work of SACHS, PFEFFER, KLEBS and others on the organic nutrition of plants, however, has not been utilized to full advantage. Fairly recently (1918) KRAUS and KRAYBILL (12) have attempted to redirect attention to such studies, and many important contributions have been made by such workers as HARVEY (9), MURNEEK (14), NIGHTINGALE (17), ROBERTS (25), JANSSEN (11), LEUKEL (13), TIEDJENS (28), ALBERT (1), NELSON (16), WELTON (29), MORRIS (30), and others. Unlike mineral nutrients, the carbohydrates and other organic foods cannot at present be supplied to green plants in a commercial way. They must be elaborated by the living plant itself. The plant producer can vary cultural procedures, however, so that the formation, utilization, storage and destruction of such materials may be controlled or directed and crop production be more or less precisely regulated with reference to quality and yields. Such cultural practices include defoliations by cuttings, pruning and grazing; fertilization, especially with nitrogenous fertilizers; etiolation by shading or other limitations of light; irrigation and combinations of these treatments.

Food reserves as they are discussed in this paper may be regarded in a general way as those organic compounds which are synthesized and maintained in forms capable of being subsequently utilized by the plant in the performance of its various functions. They are labile materials. They involve so great a variety of organic compounds that present chemical technique and knowledge afford a clue of identification and understanding to but relatively few of them. They represent an accumulation or surplus of materials in excess of the immediate requirements of the plant for growth and maintenance. Their utilization is, essentially, most abundant in an environment favorable for growth extension and in those meristematic regions of the plant where the metabolism is most active. Generally, their storage occurs during periods when the accretions in dry weight are most rapid.

¹ Contribution from the Department of Agronomy of the Wisconsin Agricultural Experiment Station, Madison, Wisconsin. Published with the approval of the director.

With the progressive enlargement of the photosynthetic area in plants, sufficient new foods are manufactured not only to provide for growth extensions but also to provide for accumulations and storage of such foods for subsequent growth. However, when photosynthesis is interrupted by frequent and complete removals of the green parts, the plant may not have an opportunity to replenish the losses of previously stored foods which were used up in its regenerative activity. Especially is this true when regeneration of new growth is stimulated by mineral nutrients, moisture and temperature, and when photosynthesis is further curtailed by shading or other forms of light deficiency. Under such circumstances the growth rate soon declines and although the levels of reserves might be sufficient to maintain the existence of the plant for some time, death eventually ensues.

The data presented in this paper, represent an attempt to correlate certain cultural procedures with the utilization and accumulation of organic foods. There is a general recognition of the ready response of plants to fertilization, moisture and to changes in temperature and light conditions, but when cultural practices involve defoliation, the responses are usually delayed and are often ascribed to some other cause even though the effect on the internal environment may be pronounced and be clearly reflected in subsequent growth. Thus alfalfa (*Medicago sativa* L.) with an abundance of stored foods may yield more during one season of growth if cut frequently rather than infrequently, but the ill-effects of frequent cutting are usually pronounced the following season. Similarly, blue grass (*Poa pratensis* L.) may be grazed closely and early for a season or more with good results, but the decline in its productivity is certain, even though not readily recognized because of wide variations in seasonal conditions, and because of the growth of other plants among the blue grass, which have not been affected so seriously by the grazing treatment. Food reserves are so intimately associated and inter-related with all other limiting factors of growth that it is often difficult to differentiate from drought, winter injury, infertility, or some other factor or factors, the particular effect a lack of such reserves may have played in developing any specific condition under consideration.

Reserves in relation to morphology and growth habits

The wide variations in the responses of agronomic plants to specific practices of top growth removal are correlated with some of their general characteristics of growth such as the duration of the succulent period and the structure and arrangement of the photosynthetic parts. PIERRE and BERTRAM (23) have studied the storage of organic foods as they affect the tops and roots of kudzu (*Pueraria thunbergiana*), a leguminous vine which is being utilized for forage in southern United States. Accord-

ing to PIPER (24) this is a very late blooming plant with a long period of succulent growth, maturing only occasionally in the latitude of Washington, D. C. PIERRE and BERTRAM report that, in Alabama, "the reserve starch and nitrogen were found to be less than half as much in the roots of plants receiving six cuttings per season for two years as in roots of plants receiving four or a less number of cuttings." During a period of two years, the weight of the roots of kudzu increased 1250 per cent. when the top growth was cut but once annually near maturity, while with six cuttings of immature top growth the roots actually decreased in weight. In the third year, the yield of top growth from the plants cut six times was only about one thirty-third of that obtained from plants cut but once annually. Other cutting treatments were tried but these will suffice to illustrate the marked responses of the kudzu plant to cultural treatments which affect the food reserves. With a relatively long period of succulence and a rapid rate of growth, several cuttings during the growing season apparently give little opportunity for sufficient accumulation of stored foods to assure the maintenance of a desirable productivity in this perennial.

The alfalfa plant has a high metabolic activity, with great ability for regeneration; and its reserves are rapidly reduced by frequent cuttings. It is obvious, on the other hand, that the reserves of small short plants such as blue grass (*Poa*) or creeping bent grasses (*Agrostis*) would be much less affected by frequent mowing with a field mower or a lawn mower, partly because of the slow recovery in vegetative extension, and particularly because of the greater proportion of the photosynthetic area remaining after each cutting. Such green remnants of herbaceous plants have the capacity to replenish, in part, the losses of reserves sustained by frequent cuttings, close grazing or other forms of removal. Under field conditions a much greater proportion of the photosynthetic area of tall, erect plants is removed by cutting or by close grazing than is true of plants whose leaves diverge largely from short branches of rhizomes or stolons, or of plants with short stems and a decumbent or rosette type of growth where the photosynthetic area consists largely of basal leaves near the soil surface. The general structure of the plant, therefore, has an important bearing on its capacity to maintain sufficient reserves for its survival under exacting grazing or cutting treatments. The persistence of blue grass (*Poa*), plantain (*Plantago*), dandelions (*Taraxacum*), purslane (*Portulaca*), creeping spurge (*Euphorbia*), and many other prostrate plants which maintain themselves in fields, lawns and pastures is thus explained in part. As shown by GRABER, NELSON, LEUKEL and ALBERT (8) twenty-two close cuttings with a lawn mower did not kill blue grass (*Poa pratensis*) though it

lessened its productivity, while only nine such cuttings resulted in death to nearly all the plants of alfalfa. Close cutting of blue grass with a lawn mower reduced subsequent productivity much more than "tall" cutting with the same implement.

In experiments conducted by the writer (7) during 1929 with blue grass seeded in 1928, the simple expedient of setting the lawn mower to cut "high" produced a thick turf free of weeds in contrast to one which was thin and weedy due to close cutting with the same frequency. An uncut remnant of one and one-half inches of the foliar parts of grasses is decidedly more effective in maintaining a satisfactory level of reserves than a half inch of such growth. This is not only significant in the maintenance of blue grass lawns where density of growth and freedom of weeds are factors which add to the value of the turf, but it has applications in the management of pastures. ALDOUS (2) indicates that the unfavorable effects of frequent clipping of prairie grasses are partially eliminated by increasing the height of clipping. STAPLEDON and MILTON (26) report that cocksfoot (*Dactylis glomerata*) plants cut frequently to a six inch level have considerably outyielded those cut to ground level. The development of tillers and roots was also much greater under the less drastic system of cutting.

The Hohenheim system

Recently, investigations have been started in America to determine the merits of the Hohenheim system of pasture management. In the main, this German system involves heavy fertilization (with mineral and especially nitrogenous fertilizers) of permanent pastures which are grazed closely at intervals throughout the year. It is evident that the success of this system of rotational grazing must make provision for the maintenance of a sufficient surplus of carbohydrates. With the stimulus of a liberal supply of nitrogen, rapid growth not only consumes organic foods for energy and cell wall materials, but the carbohydrates are utilized in the synthesis of large amounts of proteins. Heavy nitrogenous fertilization of blue grass also makes possible the stimulation of top growth at the expense of root growth, especially where grazing or cutting is sufficiently delayed to produce etiolation effects in the buds and meristematic regions of the leaves. However, by avoiding extremely early and close spring grazing and by proper extension of the intervals between grazing, the maintenance of an adequate carbohydrate reserve is readily made possible. The agronomic importance of ascertaining the responses of pasture grasses to varying "periods of rest" in rotational grazing is very evident especially under conditions of a very favorable soil and climatic environment.

While judicious fertilization may for a time stimulate the utilization of carbohydrate reserves, it is not amiss to appreciate that such stimulation

may also accelerate their accumulation when the plant is given an opportunity for such storage. Fertilization often trebles the productive capacity of blue grass and other pasture grasses grown on soils deficient in general fertility. Such enhanced potentialities in the synthesis of foods must greatly aid the green remnants which escape grazing to maintain a productive level of reserve foods in such grasses. It is primarily when these remnants are kept sufficiently reduced by close grazing or cutting treatments that the stimulation in growth from judicious fertilization is apt to hasten the decline of the reserves to a degree of serious curtailment of subsequent productivity.

Survival values and reserves

Grasses in lawns, golf courses, and pastures may exist for many years even though they receive treatments which are not conducive to the maintenance of a high reserve content. It is always to be recognized that plants with low supplies of organic foods may survive even though their capacity for survival is greatly diminished. In extreme cases, however, the maintenance of special external conditions is necessary for such survival and the constant watering and careful fertilization of golf greens and closely cut blue grass lawns are examples of such effort. Such special conditions augment the limited root growth of low reserve plants and aid the synthesizing areas which escape removal, in maintaining a level of reserve foods sufficient for the survival of the plants. Under field conditions, however, the limitations of root growth, and the modifications of the internal environment resulting from low reserves may reduce the absorptive capacity of a plant so greatly and may so increase its susceptibility to drought, winter injury, weed encroachments, insect injury and other hazards as to jeopardize its permanence. Such secondary effects often intensify the influence of low reserves on the productivity of plants, and since they appear so obvious, they may cloak this primary cause of many forms of deterioration in economic plants.

Observations made by the writer (3) in southwestern Wisconsin, where permanent blue grass grazing lands have been grazed for thirty years or more, have revealed that insect injury from white grubs (*Phyllophaga* spp.) and weed infestations appeared much more abundant in pastures which had been prematurely over-grazed or which were deficient in fertility or where soils were thin and dry due to outcroppings of limestone or flint, or where combinations of such conditions occurred. While these factors may encourage insect infestations, they also limit the amount of subterranean growth, and, in general, where such growth was least, insect injury was most abundant. The survival of economic plants, their productivity and their competitive efficiency under field conditions are dependent upon

many inter-related factors but organic reserves are among the most important.

The experiments reported in this paper show some of the correlations between agronomic practices and food reserves as they affect productivity under various soil environments and as they affect the ecological relationships of such plants under field conditions. KRAUS and KRAYBILL state that "a plant at any particular time represents the result of all the environmental forces acting upon it, and it is either in a state of equilibrium with such forces or in a state of becoming so adjusted." The adjustment of plants to those conditions which are brought about by such cultural treatments as grazing, cutting, fertilization and irrigation, is highly complex and must be approached from a study of both internal and external relations.

Cutting treatments in relation to productivity of blue grass with and without fertilization

EXPERIMENT I

A strip of land on the University Farm, Madison, Wisconsin, classified as Miami silt loam, was summer fallowed during 1925, and up to July 22, 1926, on which date it was sown with blue grass seed (*Poa pratensis* L.) at the rate of 100 pounds per acre. By fall a thick uniform growth of grass had developed to a height of about four inches. No flower stalks appeared that season nor was the grass cut. On April 11, 1927, the grass was rolled twice with a three-ton roller so as to produce a smooth surface for uniform mowing with a lawn or field mower. The area was divided into four plats of 1/35 of an acre, each designated by the letters A, B, C, and D. Plats A and C were not fertilized during the period of the experiment, but plats B and D received the following applications expressed in pounds per acre:

March 18, 1927—	220 pounds of super-phosphate (16 per cent. P_2O_5)
	140 pounds of potassium sulphate (40 per cent. K.)
	70 pounds of sodium nitrate (16 per cent. N.)
May 26, 1927—	140 pounds of ammonium sulphate (20 per cent. N.)
July 30, 1927—	200 pounds of ammonium sulphate (20 per cent. N.)
May 15, 1928—	200 pounds of ammonium sulphate (20 per cent. N.)
July 12, 1928—	350 pounds of ammonium sulphate (20 per cent. N.)

Thus, a total of 79 pounds of elemental nitrogen per acre was applied in 1927 and 110 pounds in 1928. The soil was naturally abundant in lime and in a fairly high state of fertility. The summer fallowing which preceded seeding probably increased the available fertility very considerably.

In 1927, two different cutting treatments were employed on the fertilized and unfertilized areas. Plats C (unfertilized) and D (fertilized) were cut six times with a lawn mower (set to mow about one inch above the

surface of the soil) on April 6, 29, May 11, 27, June 8 and 24, 1927. Plats A (unfertilized) and B (fertilized) were cut only once with a field mower when near maturity on June 24, 1927.

In 1928, the plats or representative portions of them were cut twice; once at maturity on July 7, 1928, and again on August 31, 1928. All cuttings were weighed in the green state and a representative sample of from 500 to 1000 grams was taken for a determination of moisture content so as to arrive at the dry weights on the basis of oven-dried grass. No attempt was made to accomplish complete desiccation although the samples were kept in a drying room for periods of from four to six days at temperatures ranging from 100° F. to 110° F. which, it is believed, provided dry-

TABLE I

COMPARATIVE AMOUNTS OF BLUE GRASS (*Poa pratensis* L.) OBTAINED FROM SIX CUTTINGS AT IMMATURE STAGES OF GROWTH AND ONE CUTTING NEAR MATURITY WHEN GROWN ON FERTILIZED AND UNFERTILIZED SOIL. BLUE GRASS SOWN JULY 22, 1926. RESULTS EXPRESSED IN POUNDS OF OVEN-DRIED GRASS PER ACRE

PLOT	FERTILIZATION	DATES AND AMOUNTS OF OVEN-DRIED TOP GROWTH REMOVED DURING 1927						
		4/6	4/29	5/11	5/27	6/8	6/24	TOTAL
C	None	244	255	332	156	133	149	1269
A	None						2930	2930
D	Abundant	146	203	342	183	236	266	1376
B	Abundant						3563	3563

TABLE II

THE INFLUENCE OF CUTTING TREATMENTS IN 1927 ON THE PRODUCTION OF BLUE GRASS DURING 1928 EXPRESSED IN POUNDS PER ACRE

PLOT	FERTILIZATION	DATES AND AMOUNTS OF OVEN-DRIED TOP GROWTH REMOVED DURING 1928				
		7/7/28			8/31/28	TOTAL FOR 1928
		LEAF GROWTH	FLOWER* STALKS	TOTAL	LEAF GROWTH ONLY	
C	None	448	152	600	603	1203
A	None	1443	279	1722	1037	2759
D	Abundant	1609	353	1962	2674	4636
B	Abundant	2630	523	3153	3315	6468

* Flower stalks include leaves diverging at nodes.

ing to a fairly uniform state. All yields were calculated on the basis of such oven-dried hay, and are given in tables I and II.

RESULTS.—The abundant rainfall, measuring 12.41 inches, during April, May and the first 24 days of June, 1927, benefited the growth of the blue grass as did also the favorable conditions of the soil on which it grew. However, when the cumulative effects of photosynthesis were diminished by frequent cuttings, the production of dry matter during a given period was

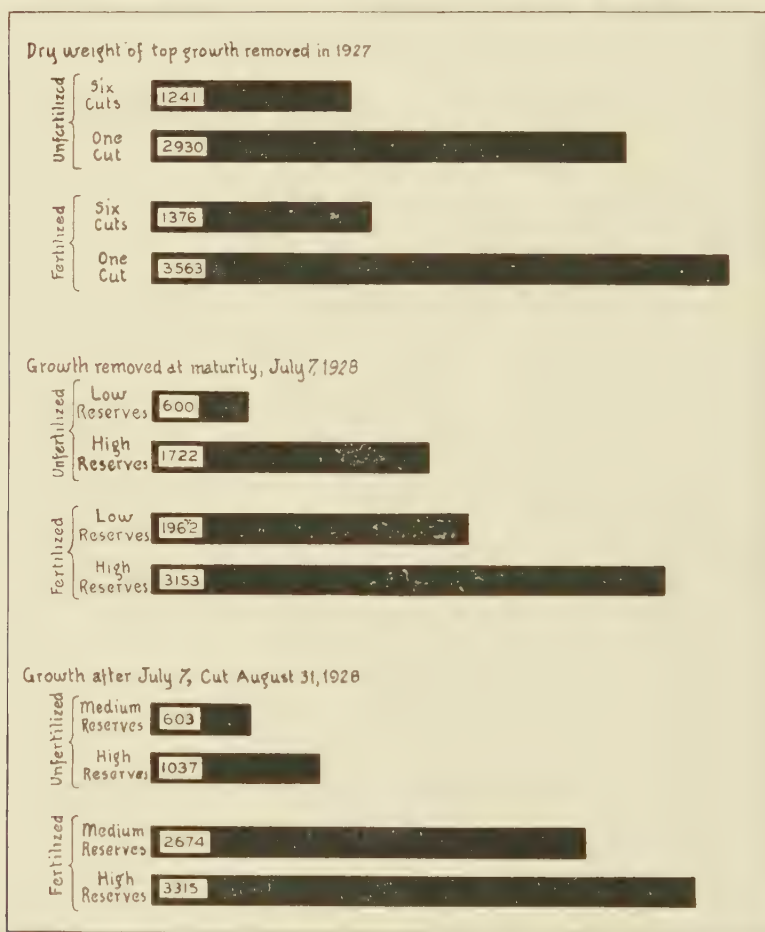


FIG. 1. Productivity of blue grass with relation to food reserves and fertilization. Six cuttings of blue grass made with a lawn mower in 1927 on April 6, 29, May 11, 27, June 8 and 24, not only gave less than half the amount of dry matter obtained with one cutting taken near maturity on June 24, 1927, but greatly reduced the productivity of the blue grass the following year as measured on July 7 and August 31, 1928. Amount of top growth removed is expressed graphically on the basis of pounds of oven-dried grass per acre.

greatly reduced. Thus, on the unfertilized soil, six cuttings of immature blue grass (figure 1) yielded but 43 per cent. of the amount of dry matter obtained from one cutting near maturity (on June 24) while with fertilization, six cuttings produced only 38 per cent. of the amount of dry matter obtained with one cutting.

The productive responses of blue grass to the fertilizations made on March 18 and May 26, 1927, were much less pronounced when six cuttings were taken during the spring and early summer period (up to and including June 24, 1927) than when one cutting was taken near maturity on June 24. Comparing the amount of growth removed from the fertilized and unfertilized plats of blue grass given identical cutting treatments, fertilization increased the yield (table I) of blue grass cut six times, 11 per cent. and that cut once, 21 per cent.

During the last six days of June and in July and August, the rainfall was only 2.43 inches so that little growth occurred during this period but in September and October when 10.45 inches of rain fell the blue grass made considerable recovery. This growth was not removed, which gave excellent opportunity for fall storage of organic foods. However, the six early cuttings prior to June 25, 1927, had a profound effect on the productivity of the blue grass in 1928. This is shown by data in table II and graphically by figure 1.

Plats B and D were fertilized again with ammonium sulphate in 1928 on May 15 and July 12, with applications sufficient to apply 110 pounds of total elemental nitrogen per acre, while plats A and C remained unfertilized. All plats were cut when fully mature on July 7, and again on the last day of August. This made possible a measurement in 1928 of the residual effects of the cutting treatments applied in 1927 on the productivity of the grass grown on the fertilized and unfertilized soil.

Without fertilization the blue grass with "high" reserves produced on July 7, 1928, nearly three times the amount of dry matter (figure 1) obtained from blue grass with "low" reserves. With fertilization the yields of blue grass with "high" reserves were 1.6 times those obtained from the blue grass "low" in reserves. Low reserves imply limited root growth, limited absorptive capacity and limited drought resistance, which conditions may well have been obviated, in part, by heavy fertilization. The designations "low" and "high" with reference to reserves are based only on previous cutting treatments and not on chemical analysis. These comparative terms are used to simplify the discussion.

It is not assumed that the deficiencies in reserves which were occasioned by the six cuttings in 1927 were alone responsible for the reduced yields on July 7, 1928, but in all probability, they were of major importance. Cutting treatments which reduce food reserves tend to retard subterranean

growth and may well lower the absorptive capacity of the plants. The marked responses from fertilization in 1928, resulting in increases of dry matter from 234 to 385 per cent., offer a striking contrast with increases of only 11 to 21 per cent. in 1927. In part, at least, such increases indicate changes in available fertility (particularly nitrogen) and losses of nutrients from the removals of grass in 1927.

The abundant rainfall during the latter part of June and in July and August, 1928, made possible another measurement of the productivity of blue grass on August 31, 1928. The fact, however, that the blue grass "low" in reserves was allowed to mature before cutting in 1928 made possible some re-establishment in the supplies of stored foods of the blue grass cut six times in 1927. For this reason, the designation, in figure 1, for the growth of blue grass after July 7, was changed from "low reserves" to "medium reserves" to approximate the probable situation of the organic foods in relation to the yields of blue grass determined on August 31. The growth removed at this time was all leaves, no flowering stalks having developed after cutting on July 7. While the grass with high reserves again yielded most, whether grown on fertilized or unfertilized soil, the differences in yields with reference to reserves are not as pronounced on August 31, 1928, as they were on July 7, 1928. Allowing blue grass with "low" reserves to fully mature apparently resulted in sufficient recuperation of the organic food surplus to increase the general metabolism and subsequent summer productivity. Whatever this may have involved in the way of additional root and rhizome development or in a greater absorptive capacity of the subterranean parts or in a greater release of energy for more rapid growth, such conditions were not sufficient to restore the full productivity of the plants as expressed by the blue grass with "high" reserves.

Reserve foods and fertilization.—The yields illustrated in figure 1 are indicative of the fact that although the soil may be abundantly supplied with available nitrogen, phosphorus, potash and all other requisites of growth, the plant may be deficient in organic materials for the greatest expression of its productive capacity. The productivity of blue grass with relation to nitrogenous fertilization is dependent, not only, upon adequate supplies of moisture, phosphorus, potash and other limiting elements within the soil, but upon the reserve foods within the plant which are also limiting factors of growth. A relatively greater response from nitrogenous fertilization occurred with blue grass having low reserves than with similar fertilization of blue grass where the reserves had not been lowered by previous cutting treatments. Fertilization during 1927 and 1928 increased the yields (taken on July 7, 1928) of blue grass with low reserves 327 per cent. in comparison with only 183 per cent. increase from the same fertiliza-

tion of blue grass with high reserves. On August 31, 1928, the increase from fertilization was 443 per cent. for the grass then having medium reserves compared with 320 per cent. for the grass with high reserves. That an explanation of such variations in the responses of high and low reserve grass to similar fertilization may rest, in part, on a greater capacity for the absorption and utilization of limited supplies of soil nutrients by plants having abundant food reserves is indicated by the recent work of STOKES, LEUKEL and BARNETTE (27). They found in the crowns of Napier grass (*Pennisetum purpureum*) which had been irrigated for three years with sewage effluent, that the quantities of dry matter, various carbohydrate compounds, total available carbohydrates and total nitrogen were approximately three and one-half times that of similar materials in the crowns of non-irrigated plants. The percentages of these organic compounds were quite similar, however, in the plants with and without irrigation. "It is apparent," they state, "that the continued large yields of Napier grass silage from the irrigated plats after the discontinuation of the irrigation with sewage effluent, cannot be explained alone on the basis of a greatly increased soil fertility of the irrigated plats nor to water alone as shown by the yields of the city water irrigated plat." The production of a larger plant system through irrigation with sewage effluent increased the elaboration of organic foods, a condition "reflected in the increased growth of the lower storage parts of the plants." Analysis of crowns subsequent to the discontinuance of irrigation, indicated that with a more extensive absorptive system and with more abundant carbohydrate reserves, a greater efficiency in the utilization of plant nutrients (particularly nitrogen) occurred.

Growth recovery.—The growth recovery of the blue grass on the fertilized plats after cutting on July 7, 1928, was much more rapid and uniform at the outset with the grass having been cut six times in 1927 than with that cut but once in 1927. During the latter part of July, 1928, the former plats of blue grass were uniformly green while the latter still appeared brown and somewhat patchy, the new growth not being thick enough to hide uniformly the dead leaves of the old stubble. On the unfertilized plats a somewhat similar contrast was apparent but was much less pronounced. It is well known that thick stands of the second year's growth of sweet clover (*Melilotus alba*) often fail to recover after late cutting. Here the young shoots and axillary buds at the lower nodes of the stems have been seriously injured by etiolation from the tall dense growth above but when this legume is grazed or clipped at immature stages, sunlight is provided for the basal leaves and buds and they continue to develop.

In this experiment, the growth of blue grass with high reserves and high fertility was so rapid and so abundant during early summer that the devel-

opment of the buds on the rhizomes or leaves diverging from the upright branches of the rhizomes was largely inhibited by the competition of the dense growth above. The basal portions of the older leaves were largely killed by the effects of etiolation and rather sudden light exposure after cutting. These factors involved delay in recovery because subsequent regeneration occurred largely from dormant buds on the rhizomes or the uninjured leaves of their branches. With less abundant top growth during spring and early summer, etiolation occurred to a much less extent and the new leaf growth was able to elongate in competition with the older growth so that when the latter was removed the leaves which partly or completely escaped mowing were in a state of growth and continued to develop after cutting.

When comparative yields on August 31, 1928, are considered, it is apparent that in this experiment, the productive capacity of blue grass well supplied with reserve foods and with abundant fertility was sufficient to compensate for the losses sustained by slow recovery resulting from the retarding effects of previous heavy growth. Such delayed recovery would, of course, prove very disadvantageous in the maintenance of lawns and of other turfs where uniformity is desired and it is a factor of importance with pasture management where heavy nitrogenous fertilization is practiced. When cutting is sufficiently delayed beyond maturity the desiccation of the old growth may so reduce its competitive effects that the development of new buds and leaves occurs and recovery after cutting is more rapid.

Ecological considerations.—The amounts of foreign growth in the plats during 1927 was very small. Just before cutting the blue grass on August 31, 1928, the weed growth was considerable, and it was removed from part of each plat (1/70 acre) with each species being counted as summarized in table III. On the unfertilized soil, the weeds were ten times more abundant in the blue grass cut six times in 1927 than were cut once that year. Fertilization, however, was a very potent factor in preventing the ingress of foreign plants. The weeds in the fertilized blue grass cut six times in the previous year were only about one-seventh of the number found in similar blue grass growing on unfertilized plats. The failure of the fertilized plats of blue grass with "high" reserves to recover rapidly gave purslane and barnyard grass a vigorous start before the grass recovered sufficiently to become a competitive factor. Both of these weeds in absence of initial competition were favored by fertilization and abundant rainfall which occurred during the summer of 1928. Purslane was present only in the fertilized plats of "high" reserve blue grass where delay in growth recovery occurred after cutting on July 7, 1928. Barnyard grass and pigweed were most abundant in these plats while other weeds were absent or

TABLE III

NUMBER OF WEEDS IN PLATS OF BLUE GRASS OF ONE-SEVENTIETH OF AN ACRE AS
AFFECTED BY FERTILITY, CUTTING TREATMENTS AND ORGANIC FOOD
RESERVES. DETERMINATIONS MADE ON AUGUST 30, 1928

SPECIES	SIX CUTTINGS 1927 ONE CUTTING JULY 7, 1928		ONE CUTTING JUNE 24, 1927 ONE CUTTING JULY 7, 1928	
	FERTILIZED	UNFERTILIZED	FERTILIZED	UNFERTILIZED
Witch grass (<i>Panicum capillare</i> L.)	8	535	26	8
Foxtail (<i>Setaria glauca</i> L.) (<i>Setaria viridis</i>)	48	260	6	44
Purslane (<i>Portulaca oleracea</i>)	0	0	280	0
Barnyard grass (<i>Panicum crusgalli</i> L.)	15	11	158	10
Horseweed (<i>Erigeron canadensis</i> L.)	0	234	0	22
Others	92	83	20	45
Total	163	1123	490	129

sparse. Foxtail (*Setaria*), witch grass (*Panicum*), dandelions (*Taraxacum*), cinquefoil (*Potentilla*), horseweed (*Erigeron*), and field sorrel (*Oxalis*) were conspicuous in the unfertilized plats of the blue grass given six cuttings in 1927.

While an invasion of weeds occurred in some of the plats during the summer of 1928, the only foreign growth which was prevalent in 1929 was white clover (*Trifolium repens*). Neither weeds nor clover appeared in any of the plats heavily fertilized with nitrogen, but in the unfertilized plats especially of the blue grass cut frequently in 1927 white clover was very abundant. The generous rainfall during the summer of 1928 made it possible for the dormant seeds in the soil to establish seedling plants of white clover which, in turn, were protected by an abundance of snow during the following winter. The soil was favorable for growth of this legume so that the external environment made possible its sudden appearance in the plats of blue grass which had not been fertilized.

The prevalence of plants other than blue grass in the plats of this experiment is somewhat analogous to the general situation observed in the pasture lands of the blue grass region of southwestern Wisconsin. The weed population of grazed blue grass may vary widely in kind from blue grass given various cutting treatments, but there are some noteworthy similarities. In general, it can be said that those factors which encourage the growth of blue grass tend to retard the ingress of weeds or clovers in

such blue grass. Thus, in the pastures of southwestern Wisconsin both weeds and white clover are generally very sparse where soils are fertile and retentive of moisture, and where the blue grass is grazed judiciously and is well supplied with reserve foods. See fig. 2 for influence of grazing on the flora of blue grass pastures. This condition tends to maintain a heavy



FIG. 2. Grazing practices influence flora of blue grass pastures. Close, early spring grazing has lowered the reserves and the competitive efficiency of the blue grass on the hillside (to right) and a heavy growth of unpalatable ragweeds (*Ambrosia*) has occurred in the pasture while with deferred and lighter grazing (left) these weeds are absent. The portions of the pastures shown above have never been plowed and although hilly the soil is regarded as being in a fairly fertile condition.

sod and during the spring season, at least, an abundant top growth, both of which are effective in preventing the entrance of foreign growths. It is not meant to imply that blue grass with optimum conditions for growth is able to exclude all forms of weed growth, but rather to indicate that when the nitrates and other mineral elements of the soil, and the organic reserves of grasses in grazed pastures are maintained in an optimum state, the competition of the blue grass is usually sufficient to prevent or retard the ingress of many undesirable plants as well as desirable ones.

The requirements of white clover for lime, phosphate, and potash are pronounced and when these nutrients are deficient in soils of grasslands, this clover is usually sparse and weeds are often abundant. The preva-

lence of this legume in southwestern Wisconsin is also influenced by climatic conditions of both winter and summer. It is probably less sensitive to drought and surely much more susceptible to winter injury than blue grass.

Many weeds such as ragweed (*Ambrosia*), dandelion (*Taraxacum*), vervain (*Verbena*), thistle (*Cirsium*), yarrow (*Achillea*), and others have a distinct advantage in competing with early and closely grazed blue grass. Such weeds may prevail because of their drought resistance or because of their general structure or inedibility or unpalatability or combinations of these characteristics which permit a partial escape from grazing even when pastures are heavily grazed. They have the advantage of being able to provide for permanence by forming seed and by maintaining reserves of organic foods. Tall plants which are palatable and with foliar parts located so as to be readily grazed, often disappear or fail to become established because with constant grazing they may not be able to form seed or maintain an adequate supply of reserve foods for their survival.

When grasses are permitted to make considerable growth before cutting or grazing, they offer greater resistance to the establishment of seedlings of foreign plants than if cut frequently. As shown by GRABER (4, 5, 6) viable seeds of legumes sown on dense sods or where accumulations of old grass had occurred, failed to establish plants; but when such old grass was burned off, or when the sod was scarified so as to provide soil contacts for the viable seeds, the seedlings were successful, if soil, climatic and other conditions were adapted to their requirements for growth. The opportunity for plants to establish themselves by seed dispersal in permanent grasslands is dependent upon factors which influence the possibilities of soil contacts for the seed as well as an environment sufficiently favorable for subsequent development. Such possibilities are often enhanced by the frequent removals of accumulations of top growth by close grazing or cutting.

There are, of course, many other external factors, such as climatic conditions, the prevalence of insects which feed on subterranean growth, the acidity of the soil, its content of nitrogen (see fig. 3) and other mineral components, its moisture holding capacity and its drainage, all of which affect the flora of permanent grasslands; but the factors which affect the internal environment of pasture grasses are also important. Under the complexities of field situations organic food reserves of blue grass as affected by cultural treatments are not only correlated with other factors which affect the quantitative responses of this plant, but such surplus foods also have an ecological significance in maintaining a high survival value and a competitive efficiency when the growth of this important grass is jeopardized by climatic, insect and weed hazards.



FIG. 3. Nitrogenous fertilization curtailed growth of white clover and weeds in blue grass. A volunteer growth of white clover occurred only in the unfertilized blue grass (left) while its absence in the adjacent plat resulted from abundant applications of nitrogenous fertilizers. Photo taken June 25, 1929.

Nitrogen relations

EXPERIMENT II

On July 14, 1925, blue grass (*Poa pratensis* L.), red top (*Agrostis alba* L.), fescue (*Festuca rubra fallax*), and timothy (*Phleum pratense*) were each sown separately in four plats of one twenty-fifth of an acre each of a Miami silt loam soil which had been summer fallowed for two years. A thick dense growth of these grasses resulted that year, and they attained a height of from three to five inches in the fall of 1925. No cuttings of top growth were made in 1925. Beginning in 1926 one-half the area of each plat was top dressed with applications of fertilizer on the dates and in the amounts per acre as follows:

- April 19, 1926—500 pounds of 4-16-6 fertilizer (4 per cent. N, 16 per cent. P_2O_5 , 6 per cent. K_2O).
- July 13, 1926— 500 pounds of 4-16-6 fertilizer.
3000 pounds of dolomitic limestone.
- March 18, 1927—125 pounds of ammonium phosphate (10.63 per cent. N).
- May 20, 1927—125 pounds of calcium cyanamid (21.73 per cent. N).
- July 30, 1927—200 pounds of ammonium sulphate (20 per cent. N).
- May 12, 1928—125 pounds of ammonium sulphate (20 per cent. N).

The fertilized and unfertilized half of each plat was divided into two equal parts of 1/100 of an acre each and a plat of each grass on the fertilized area and one on the unfertilized area was cut once with a field mower when at or near maturity on July 10, 1926. The remaining two plats of each grass were cut (with a mower) on May 22, June 12, July 10, and August 18, 1926. The yields of the grasses with these cutting treatments are given in table IV.

In 1927, the plats of grass cut four times in 1926 were given a more intensive cutting treatment by close mowings (about one inch above soil surface) with a lawn mower on April 6, May 2, 21, 30, June 8, 24, and October 28. The plats of grass cut only once in 1926 were again cut only once on June 24, 1927.

In 1928, all plats were cut at or near maturity on July 7 to measure the after effects of previous cutting treatments.

TABLE IV

NITROGEN REMOVED WITH GRASSES GIVEN FREQUENT AND INFREQUENT CUTTINGS OF TOP GROWTH. GRASSES SOWN JULY 14, 1925

GRASS	FERTILIZATION	POUNDS PER ACRE OF OVEN-DRIED GRASS AND OF ELEMENTAL NITROGEN IN GRASS								
		1926			1927			1928		
		No. CUTS	YIELD	N	No. CUTS	YIELD	N	No. CUTS	YIELD	N
Blue grass (<i>Poa pratensis</i> L.)	None	1	5050	58	1	4656	55	1	1133	13
		4	6969	199	7	2093	57	1	764	12
	Abundant	1	4867	72	1	6424	80	1	4369	68
		4	7773	193	7	3571	111	1	2804	61
Fescue (<i>Festuca rubra fallax</i>)	None	1	5916	101	1	2322	20	1	888	8
		4	5316	140	7	1559	35	1	978	7
	Abundant	1	5895	77	1	3335	45	1	3021	34
		4	6030	175	7	2844	93	1	2155	31
Timothy (<i>Phleum pratensis</i> L.)	None	1	7119	87	1	4148	39	1	1849	14
		4	4576	115	7	1172	30	1	1598	14
	Abundant	1	6369	70	1	5429	79	1	7078	62
		4	4288	107	7	1981	65	1	5319	59
Red top (<i>Agrostis alba</i> L.)	None	1	7396	116	1	3016	26	1	1250	11
		4	5917	165	7	1667	45	1	1505	15
	Abundant	1	6773	78	1	5647	54	1	5016	57
		4	6587	201	7	2862	98	1	3789	61

RESULTS.—The data in table IV are presented primarily to emphasize the important differences in the amounts of nitrogen removed with various cutting treatments of the grasses in relation to their reserve content. GRABER, NELSON, LEUKEL and ALBERT (8) state that with alfalfa “nearly twice the amount of total nitrogen was removed in the top growth cut six times at succulent stages as in two cuttings taken at the seed stage.” This, of course, occurred with alfalfa which prior to cutting was well stored with reserve foods. With grasses rather similar results have obtained particularly in 1926 when, prior to cutting, the reserves in all grasses were abundant and to a less extent in subsequent years when, with frequent cuttings, there were sharp declines in yields. The percentage of nitrogen in the grasses used in this experiment, roughly may vary from three to four per cent. in early succulent stages of growth to less than two per cent. at or near maturity. When the organic reserve of grasses are sufficient to maintain abundant productivity with frequent cuttings—as was true in 1926—the removals of such immature growth make for a very heavy draft on the available nitrogen supplies in the soil so that nitrogen itself may become the limiting factor in subsequent growth. However, when such deficiencies are avoided by abundant fertility or by heavy fertilization, the available carbohydrates are rapidly reduced and may become the limiting factors of growth under a drastic cutting or grazing treatment. This is well illustrated by the yields of 1928 where all the grasses were cut but once at or near maturity on July 7. With every grass which was fertilized the yields are decidedly less when they had been cut frequently in 1926 and 1927. Whether or not frequent cuttings may for a time result in a heavier draft on other elements of soil fertility was not ascertained in these trials, but has been established by many investigators.

ORR (22) finds “a seasonal variation in the mineral content of grasses. In Scotland they tend to be richest in July and become poorer with the advance of the season. This appears to be due not so much to the season *per se*, as to the stage of growth of the plant. At the period when it is growing most vigorously and when there is a maximum of leaf full of active protoplasm, the mineral content is at its highest. If by repeated cutting the plants are prevented from attaining maturity with the accompanying increase in fibrous material in the stems and reserve organic material in the seed, the period of high mineral content is prolonged.” Similar results are indicated by HOPPER and NESBIT (10) from studies of the composition of prairie grasses in North Dakota.

While the nitrogen content of the grasses of this experiment (table IV) was not affected greatly by fertilization in 1926 probably due to an abundance of available nitrogen in the soil, the percentage of nitrogen in the

grasses in 1927 and 1928 were, with very few exceptions, much higher where nitrogenous fertilizers were applied. Such increases occurred at mature and immature stages of growth. Cutting treatments also had a subsequent effect on the nitrogen content of the grasses. In every case except one, the percentage of nitrogen was considerably higher on July 7, 1928, in the grasses cut frequently in 1926 and 1927 than in those which had been cut at or near maturity in the two previous years. This indicates a carbohydrate-nitrogen ratio, which was more favorable for vegetative growth than it was for the production of seed. There were external indications of this in the appearance of the plats of all grasses in 1929 and 1930, but this was particularly true of fescue, blue grass and timothy.

Ecological observations.—That “low” reserves in grasses resulting from frequent cutting and low nitrogen supplies in the soil tend to lower the competitive efficiency of grass and thus favor the entrance of foreign plants, especially those with a decumbent habit of growth was made evident by the general prevalence of scattered plants of white clover (*Trifolium repens*) in all the “low” reserve and unfertilized grasses (particularly fescue and red top) during 1928. Heavy nitrogen fertilization, however, practically eliminated the infestation of this clover. Timothy, low in reserve, was also abundantly infested during the summer of 1927 with thyme-leaved spurge (*Euphorbia maculata*), a decumbent plant which largely escaped mowing, but at times added considerably to the yields. The absence of all types of foreign growth was conspicuous in the plants of grasses with “high” reserves and abundant fertility.

Observations made on June 28, 1929, show again how effectively heavy nitrogenous fertilization prevented the invasion of white clover in both the “high” and “low” reserve grasses. With the absence of fertilization the plats of grasses “low” in reserves were abundantly infested with this clover, but it was much less prevalent in the unfertilized plats of high reserve grasses. Owing to the abundance of this legume in the unfertilized plats during 1929 the collection of data on yields was abandoned.

Growth recovery.—As was true with the blue grass in experiment I, all the grasses used in experiment II were slow to recover after cutting at or near maturity and particularly where such grass had been heavily fertilized. The grasses on both the unfertilized and fertilized plats which had been cut at frequent intervals in 1926 and 1927, regenerated new growth with greater uniformity and thickness after cutting on July 7, 1928, than grasses cut only at or near maturity. With the latter a tufted type of turf was particularly evident in the plats of fescue and red top, and to a much less extent in timothy and blue grass.

A tufted growth in grasses is due largely to short rhizomes and other forms of stem growth which radiate outward and which have a tendency for

annual increments in numbers and space occupied. When such grasses are allowed to mature or approach maturity before cutting it appears as if the number of individual plants which survive competition with each other is much less than when the aerial competition is reduced by cuttings. This is true if such cuttings are at a level and within limits of frequency and duration which do not greatly imperil the existence of these plants by exhaustion of reserve foods and the ingress of weeds. With fewer plants per unit area the stand is compensated for in thickness by the more rapid and abundant growth from such plants after recovery has occurred. As previously explained, however, recovery in growth after cutting at maturity may be delayed considerably due to the etiolation and death of many basal shoots and leaves occasioned by the density of growth previous to cutting. To the contrary, when top growth is retarded by ordinary deficiencies in reserves, fertility or moisture, injury to the active basal leaves and buds from the growth above is lessened so that recovery after cutting may proceed much more uniformly even though less abundantly as far as ultimate productivity is concerned. Such conditions give the impression that frequent cuttings tend to "thicken the turf" of grasses. If such thickness is measured by the number of individual shoots or leaves per unit area and by the rate and uniformity of recovery after cutting (important factors in the management of lawns and golf courses) the contention may hold, but if this statement includes the concept of productivity as measured by the total amount of top growth produced in an extended period, it may be very erroneous.

Top growth and root development of grasses and legumes grown in greenhouse under various systems of defoliation

The efforts which were made to determine the relative amounts of subterranean growth of the several grasses grown under field conditions in experiments I and II were seriously complicated by the great difficulty of separating live rhizomes and fibrous roots from those which were dead and also from partially decomposed leaves which constituted a considerable part of the turf. To obviate these obstacles, cultures of various grasses and legumes were grown in pots in the greenhouse. This made possible certain degrees of control with reference to the external environment which eliminated many field complications occasioned by drought, the ingress of weeds, insect injury, etc. When food reserves of plants are lowered by cutting treatments of the top growth, the losses in yield under field conditions which occur subsequently, may be due not only to the limitations of growth occasioned by the deficiencies of organic foods in the plants, but to many indirect influences such as a greater susceptibility to drought and winter

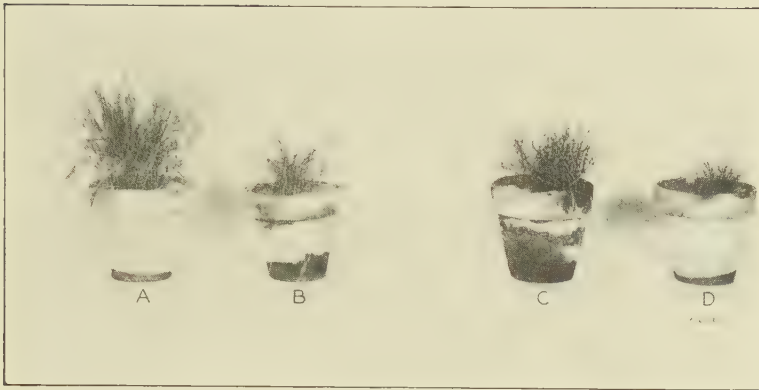


FIG. 4. Growth of red top and fescue grasses after frequent and infrequent cuttings. The grasses in pots B (red top) and D (fescue) were clipped six times between September 28 and November 13, 1928, while those in A (red top) and C (fescue) were clipped only once on November 13, 1928. The above photo was taken on December 1, 1928, after 17 days of growth in greenhouse.

injury, a lessened absorptive capacity for nutrients necessary for growth, a decrease in nitrogen supply in the soil and the invasions of weeds and other foreign growths. These complications can be avoided in greenhouse cultures so that the specific influence of the organic supply on subterranean and top growth can be more adequately measured. This was attempted in experiments III, IV and V. See also fig. 4.

EXPERIMENT III

On June 26, 1928, eight five-inch pots were filled with fertile silt loam soil. Four of these were sown with 0.6 gram each of blue grass seed, and four with 0.4 gram each of red top seed. On the same day 16 seeds of timothy were sown equidistantly in each of 9 eight-inch pots filled with similar soil. The pots were watered uniformly, and after 24 days of growth in a greenhouse, a clipping treatment was begun on 5 pots of timothy, 2 of red top and 2 of blue grass. The clippings were made one inch above the soil surface and in case of blue grass consisted entirely of leaf growth. The clippings of timothy and red top were for the most part of leaves but included some stem tissue. Seven such clippings were made on the following dates: July 20 and 25, August 2, 6, 11, 18, and 21, 1928. The grasses in the remaining pots were allowed to grow until August 24, 1928. On this date all plants were removed from pots with running water. The roots were separated from the tops. The dry weights of roots from clipped and unclipped plants at the close of a period of growth of 59 days from date of seeding are given in table V.

TABLE V

EFFECT OF CLIPPING LEAF BLADES OF SEEDLING PLANTS OF BLUE GRASS, RED TOP AND TIMOTHY ON THE AMOUNT OF ROOT GROWTH. PLANTS GROWN IN GREENHOUSE FROM SEED SOWN IN POTS OF FERTILE SILT LOAM SOIL ON JUNE 26, 1928.
 DRY WEIGHTS OF ROOT GROWTH DETERMINED ON AUGUST 24, 1928.
 TOTAL PERIOD OF GROWTH 59 DAYS

KIND OF GRASS	TREATMENT OF LEAF GROWTH	No. OF POTS	No. OF PLANTS	DRY WEIGHT IN GRAMS OF ROOTS OF 100 PLANTS
Blue grass (<i>Poa pratensis</i>).....	Not clipped	2	293	0.64
	Clipped 7 times	2	336	0.08
Red top (<i>Agrostis alba</i>).....	Not clipped	2	434	1.82
	Clipped 7 times	2	393	0.10
Timothy (<i>Phleum pratense</i>)...	Not clipped	4	44	7.89
	Clipped 7 times	5	69	0.55

Since nearly all the organic substances of the subterranean parts are first synthesized in the tops, a larger root growth from the unclipped plants was to be expected, but the increase from 737 to 1720 per cent. is much more than was anticipated. It is significant to add that the 293 blue grass plants not clipped before they were removed from the pots produced in addition to their root growth, 75 underground lateral rhizomes weighing 0.13 gram. The plants of clipped blue grass produced no rhizomes.

EXPERIMENT IV

Thirty pots (five inch) were filled with fertile silt loam soil which had been sifted to remove all coarse particles in order to facilitate later removal of fibrous root growth of the sweet clover, alfalfa, alsike clover, red clover, white clover, red top, blue grass and fescue which were sown broadcast and separately in such pots on August 28, 1928. The seedling plants of grasses and legumes were allowed to grow in the greenhouse for a month when clippings of the leaves (not stems) from the plants growing in one-half of the pots were made on September 28, October 4 and 13, 1928. On October 24, 1928, all the plants, clipped and unclipped, were carefully removed from the pots with running water, and the roots separated from the tops. Dry weights of the total top and root growth during a period of 57 days is given in table VI. The plants were watered uniformly by sub-irrigation, the pots being kept in water tight wooden flats. Nitrogen in the form of ammonium sulphate was added to the water applied so as to maintain a vigorous growth.

The pronounced decrease evident in root growth of all plants with three clippings of the foliar parts makes a detailed discussion of the data in table

TABLE VI

EFFECT OF CLIPPING LEAF GROWTH OF SEEDLING PLANTS OF RED CLOVER, SWEET CLOVER, ALFALFA, ALSIKE CLOVER, WHITE CLOVER, RED TOP, BLUE GRASS AND FESCUE ON THE AMOUNT OF TOP AND ROOT GROWTH DURING A PERIOD OF 57 DAYS OF GROWTH IN GREENHOUSE FROM DATE OF SEEDING ON AUGUST 28, 1928, TO DATE OF REMOVAL OF PLANTS FROM POTS ON OCTOBER 24, 1928

PLANT	NUM- BER OF POTS	NUM- BER OF PLANTS	NUMBER OF CLIPPINGS PRIOR TO OCT. 24	GRAMS OF TOTAL DRY ROOT GROWTH PER 100 PLANTS ON OCT. 24, 1928	GRAMS OF TOTAL DRY TOP GROWTH PER 100 PLANTS, INCLUDING THAT PRESENT ON OCT. 24, 1928
Red top	2	46	0	8.65	4.83
	2	62	3	2.17	0.33
Fescue	2	68	0	6.15	1.18
	2	59	3	1.58	0.25
Blue grass	2	66	0	3.61	0.72
	2	29	3	1.44	0.24
Sweet clover ...	1	8	0	35.13	3.92
	1	11	3	5.63	0.64
Alfalfa	2	24	0	13.46	3.00
	2	21	3	6.57	0.68
Alsike clover...	2	39	0	10.20	1.65
	2	15	3	3.29	0.39
White clover..	2	53	0	10.09	1.77
	2	31	3	2.37	0.28
Red clover	2	46	0	11.00	2.31
	2	36	3	3.38	0.27

VI unnecessary. With the loss of photosynthetic area and the utilization of reserves in the regeneration of new growth following the three removals of leaves, the amount of top growth produced with 57 days of growth following seeding was also very much less for the clipped plants.

EXPERIMENT V

Plants of blue grass, fescue and timothy were established in eight-inch earthen pots (six-inch pots in case of fescue) filled with a mixture of quartz and sifted fertile loam soil. The seed was sown on November 1, 1928. The number of plants which became established in each pot under the conditions of greenhouse culture varied from two to nine although in 76 per cent. of the pots the number of plants ranged from four to six inclusive. The pots were kept in water tight wooden flats which made possible uniform

applications of water to each plant as well as uniform amounts of potassium nitrate and ammonium phosphate which were added from time to time in solution so as to provide for optimum growth.

All the plants grew for 81 days, when on January 20, 1929, the top growth was cut one inch above the soil surface. On this date the plants were well established, but with no external evidence of inflorescences, except in the case of timothy where several spikes appeared. The older leaves of fescue had made a healthy dark green growth of from 4 to 6 inches in length, those of blue grass 6 to 9 inches while the older timothy stems had grown from 8 to 12 inches. The top growth of the plants in four pots of fescue, three of blue grass and four of timothy were cut again in a similar manner on January 30, February 5, 14, and 23. On the last date a second cutting of top growth was taken from the plants in the remaining three pots of fescue, three of blue grass and four of timothy. The five cuttings on part of the plants and the two cuttings on the remainder will be referred to hereafter as pre-cuts. Such cuttings were dried and weighed and the data are recorded in table VII.

On March 7 and March 12, 1929, clippings were again made on the grasses in all pots after which they were allowed to grow for a period of 43 days before the last cutting was taken on April 24. These cuttings were dried and weighed and will be referred to as recovery-cuts. On April 24, neither fescue nor blue grass had produced flower stalks while a few flowering spikes of timothy were present. The amount of top growth separated from the roots on April 24 is indicated in table VII. It consisted almost entirely of leaves in the case of fescue and blue grass, but of stems and leaves in the case of timothy.

On the day of the last cutting (April 24) the plants were removed from the pots and washed. The roots were separated from the top growth, and from the rhizomes in the case of blue grass, while with fescue the very short rhizomes were regarded as top growth and the fibrous root growth only was separated. Timothy roots were separated at the base of the stems.

The total period of growth for all plants from November 1, 1928, the date of seeding, to April 24, 1929, the date of the last cutting of top growth, and the separation of roots from stems was 175 days. During the first 81 days, the plants were unmolested; during the second 34 days, the pre-cuts were made, and during the last 60 days, the three recovery-cuts were taken.

Even though the grasses were well established with a root development of 81 days of uninterrupted growth before cutting treatments were begun, five pre-cuts of top growth yielded only one-third to one-half the amount of dry matter obtained from two pre-cuts. The five pre-cuts were taken (table VII) on January 20 and 30, February 5, 14 and 23, 1929. The two pre-cuts were taken at the beginning and the close of this period of 34 days.

TABLE VII

QUANTITATIVE EFFECTS OF FREQUENT AND INFREQUENT CUTTINGS OF FESCUE, BLUE GRASS AND TIMOTHY APPLIED AFTER 81 DAYS OF UNINTERRUPTED GROWTH IN GREENHOUSE. GRASSES SOWN IN POTS NOVEMBER 1, 1928

PLANT	No. OF POTS	No. OF PLANTS	DRY WEIGHT OF PRE-CUTS IN GRAMS 1929						DRY WEIGHT OF RECOVERY- CUTS IN GRAMS 1929			DRY WEIGHT OF ROOTS IN GRAMS 4/24, 1929
			1/20	1/30	2/5	2/14	2/23	Total	3/7	3/12	4/24	
Fescue	4	21	1.477	0.335	0.152	0.121	0.106	2.191	0.180	0.083	9.95	3.56
	3	17	1.620				4.780	6.400	2.210	0.413	22.98	8.87
Blue grass	3	19	2.303	0.465	0.300	0.333	0.295	3.696	0.736	0.325	21.01	13.81*
	3	17	2.140				6.570	8.710	3.025	0.623	30.74	18.95**
Timothy ..	4	16	2.633	0.550	0.252	0.215	0.435	4.085	0.511	0.192	19.74	5.39
	4	16	2.382				6.417	8.799	1.554	0.592	33.02	8.25

* In addition to this root growth the 19 plants of blue grass produced 276 rhizomes weighing 3.64 grams (dry basis) and the 17 plants ** of blue grass developed 365 rhizomes weighing 6.45 grams (dry basis).

On March 7, twelve days after the last pre-cut was made, the first recovery-cut was taken on all the plants. Five days later (March 12) a second recovery-cut was taken. Both of these recovery-cuts consisted of succulent leaf growth varying in length from 1 to 2 inches. The grasses with only two pre-cuts made a growth recovery which quantitatively was several times that of the recovery-cuts on grasses with five pre-cuts. A third recovery-cut was made forty-three days later on April 24, 1929. At this time, the amount of top and root growth was much smaller with grass plants having been given five pre-cuts instead of two. The three additional pre-cuts made on January 30, February 5 and 14 greatly decreased subsequent productivity and constituted the only controlled factor of variance in the experiment. The greater number and quantity of rhizomes in case of blue grass given two pre-cuts is substantial evidence of the ready influence which cutting treatments of top growth may exert on subterranean development.

Summary

Marked quantitative responses of root, rhizome and top growth of various grasses (blue grass, red top, fescue and timothy) grown under field and greenhouse conditions are correlated with cutting treatments which affect the internal environment. Not only did the amount of subterranean growth and total weight of top growth, ultimately, tend to vary inversely with the frequency of defoliation but reduced growth sometimes occurred for several months subsequent to excessive defoliations. It is clearly evident that the productive capacity of grasses is not only dependent upon adequate supplies of available nutrients and moisture combined with favorable light and temperature conditions but also upon the food reserves of the plant.

When photosynthesis is interrupted by frequent removals of top growth the limitations of subterranean development may involve greater susceptibility to drought, lessened absorptive capacity and increased winter and insect injury.

The capacity of the plant for maintaining a surplus of organic foods is generally enhanced when its morphology or its inedibility or unpalatability or the type of grazing or cutting is such that a considerable portion of the photosynthetic area escapes removal. Such plant characteristics along with variations in the duration of periods of succulent growth explain, in part, the wide differences in responses of various agronomic plants to specific removals of top growth.

Frequent and close removals of the succulent top growth of grasses having abundant reserves make for a heavy draft on the supplies of available nitrogen in the soil so that the first important factor of growth limitation

may be nitrogen deficiency. When regeneration is constantly stimulated by a fertile soil or by abundant mineral and especially nitrogenous fertilization, the carbohydrate reserves are rapidly consumed and with slight opportunity for replenishment they often become the principal factors limiting growth.

When an abundant growth of blue grass occurs with fertilization and delayed cutting, the recovery after such cutting is often slow and uneven due, in part, to etiolation and the death of many basal leaves occasioned by the dense growth above. Such delay in recovery may, under favorable climatic conditions, encourage the ingress of certain weeds and may prove significant in the management of heavily fertilized pastures or of turfs and lawns where uniformity is desired.

Organic food reserves have a significant ecological relationship, especially with reference to the flora of grasslands. Aside from the occurrence of weeds with delayed cutting, the maximum competitive efficiency of beneficial grasses, as measured by invasions of other plants among them, occurred generally, when optimum fertility was combined with those practices of cutting or grazing which maintained a productive level of reserve foods in such grasses.

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